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# REPORT OF CONFERENCE ON THE SUPER

Work done by:
(all conferees and members of T-7)

Betts, Col. A. W.
Bradbury, N.
Bretscher, E.
Flanders, D. A.
Frankel, M.
Frankel, S. P.
Froman, D. K.
Fuchs, K.
Hamming, W.
Hurwitz, H.
Judd, D.
Koller, J.
Konopinski, E. J.
Landshoff, R.
Manley, J.
Mark, C.
Marvin, C.
Metropolis, N.
Miller, H. I.
Morrison, P.
Mullaney, J.
Nordheim, L. W.
Placzek, G.
Reines, F.
Richtmyer, R. D.
Serber, R.
Teller, E.
Tuck, J.
Turkevich, A.
Ulam, S. M.
Von Neumann, J.

Written by:

Bretscher, Egon
Frankel, S. P. Stanley
Froman, D. K. Darol
Metropolis, Nicholas C
Morrison, Philip
Nordheim, Lothar Wolfgang
Teller, Edward
Turkovich, Anthony
Von Neumann, John

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By Bryan S. Kill May 17 1971
(Signature of person making the change and date)

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COVER SHEET

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Except for deletions required to guarantee that no classified aspect of the matters dealt with might be disclosed -- whether of a detailed or a general nature -- and except for easily identifiable interpolated notes intended to restore the context and provide a measure of continuity where a whole page or more has been deleted, the attached pages are a facsimile (xerox copy) of the text of Report LA-575. This edited version of the report has been prepared by J. Carson Mark with the assistance of Mrs. B. Kelly, both of the Theoretical Division Office of the Los Alamos Scientific Laboratory.

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## FOREWORD

A conference was held at Los Alamos April 18, 19 and 20, 1946, to review work that has been done on the Super for completeness and accuracy and to make suggestions concerning further work that would be needed in this field if actual construction and test of the Super were planned. Basic theory and construction of the proposed design, discussed in report, LA-551, were presented in detail by Teller and members of Group T-7, and were then discussed in detail by the conferees. The ensuing discussions of the conferees, together with a brief description of the model, are summarized in the present report which has been compiled from parts written by several of the conferees. These parts were read by as many as possible of the other conferees prior to publication and, although it was not possible for all of the conferees to review the entire report in manuscript, it is believed that its contents are essentially the unanimous opinions of those attending the conference.

The general plan of the report is as follows:

Part I is a general discussion of thermo-nuclear reactions and their use in the Super Bomb.

Part II is a discussion of the proposed model and its principle of operation. In this connection it should be remembered that this model was chosen for ease and reliability of the theoretical calculations rather than for efficiency of use of expensive materials or engineering simplicity.

Part III contains criticisms, alternative arrangements and additional calculations discussed at the conference. Many possible alternatives have been considered in the past by members of Group T-7 and were discarded at the time of writing of report LA-551 in the interest of definiteness of the model, and only those alternatives are described here which were actually

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discussed at the conference.

Part IV outlines very briefly experimental programs that would need to be undertaken before construction and test of the Super.

Part V discusses possible peaceful applications of thermonuclear reactions. This discussion is much more speculative and much farther removed from actual realization than the rest of the report, but is included for the sake of completeness.

Part VI contains the conclusions reached by the conference relative to feasibility of the Super and the magnitude of the task that remains if a Super is to be constructed and tested.

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## PART I - INTRODUCTION

### Section 1. Thermo-nuclear Reactions

With the first quantitative successes of nuclear physics, years before nuclear fission was discovered, it became clear that large-scale release of nuclear energy took place in the stars as the result of collisions caused by the temperature motion of the nuclei of hot matter. During the earliest serious investigations of explosive nuclear processes, carried on even before the establishment of the Los Alamos Laboratory, much attention was given to the production of artificially initiated thermo-nuclear reactions as an explosive energy source. Two general properties of such phenomena were early recognized. First, decisive importance of hydrogen isotopes, especially of the relatively available deuterium. Deuterium provides a fuel for the thermo-nuclear reaction as uniquely appropriate as is uranium for the fission chain reaction. It seems likely that no other naturally-occurring isotope is a suitable thermo-nuclear fuel,

Second, the nature of the physics of this type of nuclear reaction is qualitatively different from the neutron physics involved in the now familiar fission chain. The nuclear properties of the key materials are still fundamental in that the energy is supplied by nuclear reactions; but control and understanding of the phenomenon involves purely atomic consideration to a much greater extent than was the case in the fission bomb. What the reaction depends on is the complex behaviour of matter at extremely high temperatures. For prediction, then, the primary requisite is a deep insight into the general properties of matter and radiation derived from the whole theoretical structure of modern physics.

Some practical confirmation of such theories is contained in functioning of fission bombs with efficiencies not greatly different from those expected.

Section 2. The Super Bomb

The energy of the thermo-nuclear reaction arises essentially from the combination of deuterium nuclei into alpha particles. Deuterium fully consumed yields energy several times that from the same weight of fissionable material. Moreover, the unit cost of deuterium (say $0.20 per gram) is comparable, not with that of fissionable material at hundreds of dollars a gram, but with that of normal uranium. The initial cost of a minimum deuterium explosion is fixed, however, by the cost of initiating it, which under present knowledge is

. But the most striking property of such a reaction is that its scale is limited — if it proceeds at all — only by the amount of deuterium fuel provided. Thermo-nuclear explosions can be foreseen which are not to be compared with the effects of the fission bomb, so much as to natural events like the eruption of Krakatoa. The energy released, for example, by even the

, is $2x10^{23}$ ergs, and values like $10^{25}$ ergs for the San Francisco earthquake may be easily attained. This catastrophic property has given rise to the name of the device used throughout the work. The deuterium thermo-nuclear explosion has been called the super-bomb.

Section 3. Effects of the Super-Bomb.

It goes without saying that the release of such enormous quantities of energy in very short times (a small fraction of a microsecond is time enough to consume a large mass of deuterium) will produce new and little-known destructive effects. Only detailed study could produce reliable estimates of the damage induced by such explosions. But even the most general considerations are enough to

Following page 5:

[Discussion of various effects of devices of specified yield continues to middle of p. 7.]

Section 4. Related Problems

The problem of the controlled release of thermo-nuclear energy is still unsolved, though some thought has been given to it. No proposal yet made seems entirely plausible, but the process is not at all theoretically excluded. The great total availability of deuterium, compared to uranium, and certain other advantages, such as the possibility of making a neutron source relatively free from gamma rays, make the scheme attractive. The possibility of the super-bomb reaction is in some ways independent of the possibility of controlled reactions; in the end either may be accomplished without the necessary success of the other.

It is to the discussion of the feasibility and the methods of designing such a weapon that the remainder of this report is devoted.

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Following page 8:

[PART II - THE SUPER MODEL; GENERAL DESCRIPTION is the heading at the top of p. 9. A description of the model and its mode of operation starts at this point and ends on p. 15.]

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PART III - DISCUSSION OF THE MODEL

This part of the report contains discussion of criticisms made at the conference, alternative arrangements suggested, and some additional calculations on the model that were not finished at the time of writing 1A-551.

Section 10.

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Following page 16.

[The balance of p. 16 and pp. 17, 18 and most of p. 19 are involved with discussion of details of the device unrelated to those aspects for which help was sought from the ENIAC.]

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Section 11.





Some of the questions to be discussed here are: (1) what range of temperatures are required; (2) what amounts of material must be heated; (3) what is the optimum ; (4) what is the hydrodynamical behavior of such systems.

The proposed problems do not lend themselves to either analytical methods or similarity treatment; it was necessary to adopt numerical methods. The extensive calculations have been done on a new electronic calculator, called by its inventors the ENIAC.

The first set of problems was in the nature of a preliminary survey.

The set of equations governing the behavior of the system includes: (1) a description of the hydrodynamical motion;

; (2) the spatial distribution of temperature as a function of time. The corresponding equation consists of several parts. Firstly, there is the . Secondly, there is the expression to Thirdly, the loss of energy by

. . . Fourthly, there is an integral expression that describes the energy production from D-D reactions and the manner in which the energy is deposited spatially; the branching ratio of the D-D reaction is taken as unity throughout, independent of energy. Finally, a second integral gives the energy produced and its dissemination for the secondary D-T reactions; the energy of the resultant helium nuclei is assumed deposited locally

(3). as a function in space and in time is calculated.

Section 12. -- Calculations

For this report, in Table I, we shall merely summarize each problem by giving the initial conditions,

the number of cycles to which each problem was carried , and whether the results thus far obtained indicated a self-sustaining reaction. These first sets of calculations were primarily designed for

A detailed description and discussion of the results will be given in a forthcoming report.

Following page 21.

[The Table referred to on p. 21 occupies p. 22 and lists the conditions applying in Problems A, B, C, D, E, F, G, H, K, L, N -- which are also those listed in the TABLE of p. 28 of LA-525, and for which some results are presented in the graphs of Figs. 6 - 16 of LA-525.]

Section 13. Calculation

When the model given in LA-551 began to crystallize it was decided to carry through two problems which would be more directly applicable. Here we assumed

In problem P,

in R,

Problem P was followed for more than 50 cycles and R for 45 cycles. The accompanying graphs show some of the results for Problem R. The results for Problem P are quite similar.

Figure 2 shows the temperature at the end of every five cycles

Figure 3 shows the spatial distribution of

Figure 4 illustrates the variation in

with time.

Section 14. Conclusions

Neither Problem P nor R were calculated out far enough to say unequivocally that The likelihood that the system considered in Problem R would is based on the following considerations:

1. As indicated in Figure 2, all increase in temperature with time.

2. The temperature distribution in Problem R may be compared with the results of calculations for a case where

The calculations were by hand (see forthcoming report by S. Frankel, et al) in a manner similar to that used by the ENIAC for the cases discussed in the first part of this report. They indicated that (even with the slightly less favorable values accepted at that time) the system would ignite —

It would appear to be safe to conclude that the temperature in Problem R would continue to rise

3. In an igniting deuterium system, one would expect the tritium concentration to increase with time.

Figure 4, moreover, shows that after , the total amount of tritium will probably start rising. We have not, however, conclusively demonstrated, the energetic divergence of the reaction in Problem R. This is illustrated in Figure 6, which gives

Moreover, another pessimistic argument is that, since the ENIAC calculations were started, the best interpretation of the measurement has lowered the values below those used.

The following assumptions must be considered as optimistic if the results of Problem R are to be applied to the model discussed in LA-551:

The argument is proposed, however, that an increase in would convert the real situation into one comparable to the model for which the calculations were made.

We have estimated the seriousness of this omission for Problem R and its application to the model of LA-551 by calculating the effect according to the methods of Hurwitz (LA-553).



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We conclude that the omission of this effect is not too important for Problem R.

On the basis of the above considerations we claim that the use of a

will probably be ignited

in a manner not too dissimilar to that indicated by Problem R.

Section 15. Alternative Arrangements

In the model proposed, the was so arranged as to have a minimum . This is desirable in order to have an optimum

On the other hand, this arrangement

Some compromise solution which conserves as much as is feasible of the first-mentioned advantage and avoids as much as possible of the last-mentioned drawback seems therefore indicated.

Two geometries which might affect such a compromise are the

Following page 27.

[On pp. 28 and 29 the possible 'Alternative Arrangements' are discussed in detail, and further possible variations on the model which were suggested during the conference are described and discussed on pp. 30, 31, 32.]

## PART IV – EXPERIMENTAL PROGRAM, DEVELOPMENT AND TESTING

### Section 18. Experiments in Nuclear Physics

#### 1. Reactions Involving Tritium

Good measurements of the reaction yield of the T-D processes are now available in the energy region from 15 to 125 Kev. For technical reasons, thick targets ($D_2O$) have to be used at those low energies. The cross section is obtained from the following experimental data, with the help of the relation:

$$\sigma = K \, (dN/dE)_E \, (dE/dx)_E$$

where K is a known numerical constant, dN/dE the rate change of disintegrations with bombarding potential and dE/dx the energy loss per unit length of the incident particles in the target. Whilst dN/dE is known with considerable certainty, dE/dx has been obtained by extrapolating old measurements by Gerthsen and his pupils to low energies. A careful analysis shows certain inconsistencies in the determinations of Gerthsen, particularly at low energies where the experimental difficulties are greatest. This makes extrapolation still more dubious. Unfortunately, this is just the region where we would like to know the cross section best,

. It is not possible to make a reliable statement about the errors with which dE/dx is afflicted at these low energies, but it is hardly likely that this quantity is in error by more than a factor of two. Since the cross section is proportional to dE/dx, it is affected in the same proportion. At higher energies one would expect dE/dx to be more reliable, because no extrapolations are required.

From this, it results that it is imperative to perform really reliable energy loss determination for tritium in the lower energy region.

The gap between 125 and 200 Kev remains still unexplored and it would help to round out knowledge of the D-T cross section to cover also this region. It would make the prediction,

, much more reliable.

Other reactions involving T are likely to be of lesser importance. There is a chance that the $T+T \rightarrow \alpha+2n$ reaction cross section is large enough to make a sizeable contribution to the energy released

. Scattering cross sections of 1 Mev T nuclei in D and some other light materials would also be of interest.

2. Cross Sections of 14 Mev Neutrons produced in the T+D reaction have not been sufficiently investigated so far. Only crude data exist on the scattering of these neutrons in D. Nothing is known about the dissociation of D by these fast neutrons or about fissions produced by them. It would be important to get reliable information on all these points.

Scattering cross sections of the 14 Mev neutrons in other materials would be also interesting and it would be further desirable to find out what nuclear reactions these fast neutrons can induce in various materials. These latter questions call for a widespread experimental program which is of less immediate importance, but which may lead to discoveries facilitating the construction of the Super.

Section 19.

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Following page 34.

[Various problems concerning construction of the model are discussed, beginning on p. 34 and continuing through p. 41.]

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## PART V - PEACETIME APPLICATION OF THE D D REACTION

### Section 25. Controlled Reactions

Barlos and Becker have proposed to utilize the D+D reaction at a low temperature, namely, at a few hundred electron volts. At this temperature, the radiation emitted by the electrons is much greater than the energy produced by the nuclear reaction. However, the radiation instead of being lost in practically every case, will be reabsorbed and radiation losses occur only from the surface. Under these circumstances it would not be necessary to use pure deuterium, but any chemical compound such as heavy water would be adequate. The assembly would have a critical size determined by the requirement that the surface should be sufficiently small as compared to the volume.

The difficulty in this scheme is that it requires at least a temperature of 200 eV if the reaction is to proceed in a not too great volume and at an appreciable rate. At this temperature, the radiation pressure alone would be so great that no vessel could hold the material together.

If on the other hand one tries to build an arrangement which is not supposed to function steadily but which is supposed to explode, then only a very short time will be available for the nuclear reaction to take place. During this short time, much less energy will have been produced than was needed to bring the material to its original high temperature needed to start the reaction.

An entirely different possibility of a controlled D+D reaction was discussed at the conference. One would heat very dilute deuterium gas (about $10^{-9}$ X liquid density) to a temperature above the ignition point.

That is a temperature of perhaps 30,000 or 40,000 eV. The radiation would be allowed to escape and therefore the radiation pressure would not build up. On the other hand, the pressure of the gas would remain low in spite of the high temperature because of the low density of the gas. This scheme presents two extremely great difficulties which however may not be insuperable. One is, to heat this gas to the required high temperatures. This could possibly be done by electrical means. But the fact that so far the highest temperatures obtained in this way are of the order of 10 eV shows how great a development job is ahead.

The other difficulty is that at the low density considered, conduction losses will be extremely great and will instantaneously quench the reaction. It is hoped that by using magnetic fields one may cut down conduction losses to the point where a continued reaction is possible, but the theory is not worked out to the point where a prediction about feasibility could be made.

It seems that the possible use of D+D reactions as neutron sources or power producers is not yet excluded. Much more thought and some new ideas are needed. A more widespread circulation of the fundamental physics of the thermo-nuclear reaction should lead to better knowledge of its possibilities for such uses.

## PART VI - CONCLUSIONS

On the basis of the discussion during the conference, the following conclusions were drawn by the participants:

It is likely that a super-bomb can be constructed and will work. Definite proof of this can hardly ever be expected and a final decision can be made only by a test of the completely assembled super-bomb. The main reason for doubt is

There is at present no indication that any of the basic physical processes has been neglected, nor is it considered likely that any additional basic process will need to be taken into consideration.

It was felt that a detailed calculation would have to be undertaken to learn to what extent the thermo-nuclear explosion will

While it seems that all relevant physical facts have been discussed, and while

, it was believed that a detailed calculation of this point would add to the strength of evidence for the feasibility of the super.

The detailed design submitted to the conference was judged on the whole workable. In a few points doubts have arisen concerning certain components of this design. These doubts have been discussed above. In each case, it was seen that should the doubts prove well-founded, simple modifications of the design will render the model feasible.

Further modifications of design were suggested with a view of making more efficient use of the materials. None of these modifications has been worked out in detail. In some cases detailed design will have to depend on experiments and extended calculations. An obvious comment at this point is that attention be given to developments in high speed electronic calculators. Work thus far has shown that the complexity of the problems require at least an instrument like the ENIAC.

It seems therefore very likely that a super can be constructed and that the following materials will be needed for its construction:

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The report summarizes the work which has so far been done in this field on the Manhattan Project. The undertaking of the new and important Super Bomb Project would necessarily involve a considerable fraction of the resources which are likely to be devoted to work on atomic developments in the next years. A statement of the potentialities of the super as a weapon, and an estimate of the cost of answering, in practice, the questions still unsolved, have been included. But we feel it appropriate to point out that further decision in a matter so filled with the most serious implications as is this one can properly be taken only as part of the highest national policy.

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Following page 46.

[Page 47 carries Fig. 1, which is a sketch of the model. Pages 48 through 52 carry Figs. 2 through 6 which are graphs showing various results of Problem R. These are identical with the graphs showing the results of this problem in LA-525, with the exception of one curve given here and not included in LA-525.]